A Glimpse to the Future of RFID Technology Guest Editorial of the Special Issue on IEEE RFID-TA 2019 Conference

IN THE era of the forth industrial revolution, the need for an enforcing collaboration between industry and academia is a key issue to develop the future Radio Frequency Identification (RFID) systems. The need of interconnected people and objects open the way to new smart systems and applications, where the RFID system represents an enabling technology.

In such a framework, the IEEE JOURNAL OF RADIO FREQUENCY IDENTIFICATION (JRFID), established in 2017, uses to collect the extended version of selected papers coming from the annual IEEE conferences on RFID. In particular, this Special Issue holds the extended contributions of papers presented at the *IEEE RFID-TA 2019 Conference*, hosted in Pisa, Italy, on September 25–27, 2019. The IEEE RFID-TA is a flagship conference in the area of RFID, which provides the platform to share the research and experience in the wide aspects of RFID technology and applications.

The Hosting Town and the Conference Venue: The city of Pisa is located near the Tyrrhenian Sea in north-western Tuscany, along the banks of the Arno river, and approximately 80 Km west of Florence. Known worldwide for the extraordinary monument of the Leaning Tower (Fig. 1), Pisa is a place of artistic treasures, a heritage of its millenary history whose point of highest splendor dates back to the age of Maritime Republics (12th century).

Fig. 1. The city of Pisa: detail of the Leaning Tower through a fishbowl.

Visitors to this eminent University city discover not only art, culture and history, but also an evocative environment (natural parks, seacoast, and mountains), folklore, excellent restaurants, and fancy shops. The Conference venue, "*Le Benedettine*" (Fig. 2), was in a very suggestive and peaceful context, near the church of *S. Paolo a Ripa d'Arno*, overlooking the Arno river in downtown Pisa. It is an old Monastery of S. Benedetto, originally arose in the early twelfth century on the Pisan coast as a hermit community.

The Conference Program: The 10th edition of the IEEE RFID-TA Conference has been the first *Italian Edition*. It started with a full day dedicated to companies developing RFID components and RFID-based systems and applications. During that day, a Workshop on "News from the RFID Industry", a contribution from the Platinum Sponsor (Lab ID, Italy), and the unique special session on "RFID for the Made in Italy" were hosted. System integrators, manufacturers and end-users have contributed with invited talks, exhibitions and sponsorships. Well-known Italian brands, such as Valentino S.p.A., Ca' del Bosco, and ID-Solutions s.r.l. discussed RFID applications in the vinery, fashion and food sectors.

On the following two days, more than one hundred oral speeches were scheduled and divided in fourteen technical sessions. In particular, 108 papers were presented and included in the conference proceedings, with an acceptance rate of 87%, with respect to the 124 submitted papers. Such a great result was possible thanks to the hard work of 27 Session Organizers, who convened 13 Special Sessions, inviting experts in the field of novel antenna design, localization systems, sensing, biomedical applications, wireless power transfer and energy harvesting, RFID emerging applications. Each paper was reviewed by at least two members of the Technical Program

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Fig. 2. IEEE RFID-TA 2019 conference venue "*Le Benedettine*".

Committee composed by more than 50 esteemed researchers and experts in the RFID sector.

Among the technical sessions, for the first time, the conference featured a special session dedicated to recognize the women's contribution to the RFID sector, "RFID Ladies: spotlight on recent scientific and industrial advances of Women Engineers", and a special session to promote the activities of the "IEEE Council on RFID" around the world, "RFID R&D Activities in IEEE Chapters".

Besides, two outstanding keynote speakers delivered a plenary talk. The Keynote Speech of Prof. Smail Tedjini entitled "Advances in RFIDs" focusing on recent development of such a technology was organized in collaboration with the Italian National Committee of URSI. Also, Prof. Nuno Borges Carvalho presented a talk entitled "A Wireless World Without Batteries", discussing future wireless paradigms that will be changing soon with 5G and beyond technologies.

Competitions for the Best Paper Award and the Best Student Paper Award were also organized. The work by Buffi *et al.* entitled "A Phase-based Method for UHF RFID Gate Access Control" received the *Best Paper Award*, while other two papers, "An Ultra-wideband Batteryless Positioning System for Space Applications" by Dardari *et al.* and "An approach for Synchronous Reading of Near-Field Chipless-RFID Tags" by Paredes *et al.* received an honorary mention as Best Paper Award. Best student paper competition has rewarded the following papers: "Learning Gestures Using A Passive Data-Glove With RFID Tags" by Kantareddy *et al.* (1st place), "Beam Scanning UHF RFID Reader Antenna with High Gain and Wide Axial Ratio Beamwidth" by Chen *et al.* (2nd place) and "A Phase-Based Method for Mobile Node Localization through UHF-RFID Passive Tags" by Motroni *et al.* (3rd place).

The Special Issue: Among the conference papers, 27 contributions have been extended and published on this Special Issue [see items (1)–(27) in the Appendix for the complete list of articles], coming from Germany, United States, Greece, Italy, China, United Kingdom of Great Britain and Northern Ireland, Finland, Russian Federation, Taiwan, Spain, France, and Portugal. They addressed several topics such as localization systems, novel antenna design, tag sensing, wearable sensors, augmented RFID systems and chipless, which represent the current hot topics in the RFID research field, so giving a glimpse to the future of the RFID technology.

In the framework of localization systems, both the tag positioning [items (1)–(4) in the Appendix] and the vehicle tracking/navigation [item (5) in the Appendix] have receiving increasing interest. The centimetre accuracy that can now be obtained is the result of optimized phase-based methods [items (1)–(5) in the Appendix]. When addressing the tag localization issue in dynamic environments, where either the tag or the reader is moving, it is possible to exploit the synthetic-array approach to overcome the lack of bandwidth of the UHF-RFID systems, allowing for accurate positioning. This is the case of the works presented in [items (1)–(3) in the Appendix]. In particular, two of them, [items (1) and (2) in the Appendix], considered robot-based systems to perform accurate 3D localization. In [item (1) in the Appendix], Tzitzis *et al.* proposed the *Phase ReLock* method with a special unwrapping technique, to employ for tag positioning through autonomous RFID robots adopted within the RELIEF project. In [item (2) in the Appendix], Bernardini *et al.* proposed a robot-based system equipped with two antennas for tag 3-D positioning at a reduced computational cost, thanks to the application of the particle swarm optimization. Instead, a proper modification of the classical synthetic-array method is proposed by Di Giampaolo and Martinelli in [item (3) in the Appendix]. In particular, they designed a multiple baseline approach after eliminating measurements strongly affected by multipath, to locate tags through moving reader antennas. In the context of the intelligent transportation systems (ITS), Zhang *et al.* [item (4) in the Appendix] designed a multi-frequency based phase-difference-of arrival (PDOA) algorithm for tag ranging, while Unterhuber *et al.* [item (6) in the Appendix] investigated the speed bound which allows for the detection of tagged vehicles.

Finally, other interesting works defined localization solutions through systems operating at 5.8 GHz [items (1)–(8) in the Appendix]. Dardari *et al.* presented an ultra-wideband (UWB) remote-powered positioning system for potential use in tracking floating objects inside space stations [item (7) in the Appendix]. It makes use of battery-less tags which are powered-up and then addressed through wireless power transfer in the UHF band. Furthermore, it embeds an energy efficient pulse generator in the 3-5 GHz UWB band. The system has been mounted on the ESA Mars Rover prototype to demonstrate its functionality and performance, within the LOST European project. Akbar *et al.* [item (8) in the Appendix] presented a novel motion capture system based on a sensor-fusion approach to perform 2-D position and orientation estimation as well as tracking. The technique is implemented using a 5.8 GHz RFID system that consists of three readers and a customized tag equipped with a 3-axis accelerometer, 3-axis gyroscope and 3-axis magnetometer.

Among the more widespread applications, during the last few years, the number of biomedical and wearable RFID sensors have been constantly increasing [items (9)–(15)

in the Appendix]. Besides solutions employing Near-Field-Communication (NFC) [item (9) in the Appendix], sensors adopting the UHF-RFID technology have been designed with the advantage of an increasing reading range [items (10)–(15) in the Appendix]. In [item (9) in the Appendix], Di Rienzo *et al.* analyzed the use of NFC for ultra-low-power communication in wearable devices for biomedical applications. The goal is to verify whether NFC technology can support the heterogeneous requirements of different biomedical use-cases, by focusing the attention on the energy harvesting capabilities to evaluate the feasibility of designing battery-less devices. The authors showed that NFC adoption in different biomedical applications is possible, as they can ensure proper reading frequency and distance. To demonstrate this, they provided a proof-of-concept implementation, namely an NFC-based sensorized glove for work safety able to monitor the external temperature in a continuous manner.

UHF-RFID sensor tags for implantable [item (10) in the Appendix] and biomedical [items (11) and (12) in the Appendix] applications have been proposed in this Special Issue. In [item (10) in the Appendix], Makarovaite *et al.* presented a novel sensor to overcome the low-efficiency issue caused by the capacitive loading of the human tissue which typically reduces the efficiency of wearable sensors. It consists of a convoluted half-wave dipole operating in the UHF band which provides read distances above 0.5 m within a body phantom. It was able to detect simulated early to mature Candida albicans biofilm growth when mounted upon a voice prosthesis, up to a 30 μm biofilm thickness. In [item (11) in the Appendix], Horne and Batchelor investigated a methodology for using UHF RFID communications to stream sensor data from an on-body location, at speeds and integrity rates which ensure that reliable data analysis can be achieved offline or by supplementary computing power in real-time. The results in both synthetic loading, and real-life scenarios indicated high standards of performance which are comparable to industry standards using more power-demanding communication techniques. In [item (12) in the Appendix], Miozzi *et al.* investigated the performance and durability of epidermal RFID tags, equipped with a self-tuning RFID IC, and based either on copper wires or conductive yarns. The tags are deployed onto an ultra-thin stretchable and transparent substrate to achieve conformability to body discontinuities. They easily reached a read range of 1 m in the UHF band, while up to 2 m can be reached in some favourable configurations. This new family of epidermal tags is moreover suitable for low-cost and large-scale manufacturing through the widely available machines used for wire-laying, bending, and shaping.

Besides, wearable tags have been proposed in [items (13)–(15) in the Appendix]. In [item (13) in the Appendix], Yu *et al.* investigated the several factors affecting the performance of embroidered antennas. They verified through both a simulated and a measured analysis that slotted-patch UHF RFID antennas fabricated with low resistance yarns are more sensitive to geometrical variations, such as bending and curving, while meander line dipole antennas are more sensitive to stretching and elongation. Thus, RFID tags equipped with these embroidered antennas can be utilized as battery-less passive deformation sensors for human movements. In [item (14) in the Appendix], Mehmood *et al.* designed a passive UHF-RFID-based strain sensor, for simple and efficient body movement monitoring. The proposed RFID sensor is fabricated from electro-textile materials and can be easily integrated into clothing. The sensor platform has an integrated reference tag, in order to avoid the effects of reflections or external disturbances on the sensor tag performance. It reached an on-body read range of 1 m, which significantly changes with the arm elongation. Thus, the sensor functionality can be based on variation of the sensor-tag backscattered-power percentage, by suggesting an efficient future way to turn human gestures into inputs for digital devices. In [item (15) in the Appendix], Singh *et al.* presented a wearable dual-band quasi-Yagi RFID-reader antenna designed for being incorporated into a smart glove. The antenna dual-band capability allows the integration of both the RFID reader at UHF band and a wireless data link at 2.4 GHz, into a single compact and wearable device. Dipole and loop antennas are combined into a quasi-Yagi structure to be placed on a hand back, in order to detect tagged objects, close to the hand palm and fingers, during the operator normal activities.

The design of advanced antennas for RFID system is always a hot topic, as confirmed by the high number of related papers submitted to the conference and to this Special Issue [items (16)–(24) in the Appendix]. Two papers are focused on High Frequency (HF) band device and antenna design [items (16) and (17) in the Appendix]. In particular, in [item (16) in the Appendix], Le *et al.* proposed a miniaturized cost-effective RFID/NFC antenna for a microelectronic measurement system, that is printed on different flexible carrier substrates using a new and low-cost Direct Ink Writing (DIW) technology. In [item (17) in the Appendix], Chen *et al.* presented a simple NFC RF performance measurement method based on ISO/IEC 14443 standard. Specifically, the measurement procedure of three test items were described, namely off-keying duration time evaluation, H-field strength measurement and NFC system RF performance evaluation. In [item (18) in the Appendix], Shirokov focused this article onto distance-to-tag measurements in extended operation range. In such a paper, the phase radio engineering system with homodyne signal conversion was proposed for implementation, that can identify and localize several objects simultaneously. The described amplifier resulted to be useful in active 433 MHz transponder design for RFID systems.

Specific interest is devoted to the antennas and RFID systems at the UHF band, namely 865-868 MHz in Europe and 902-928 MHz in the United States [items (19)–(21) in the Appendix]. In [item (19) in the Appendix], Colella *et al.* discussed some of the advances in additive manufacturing 3D-printing for electromagnetic applications, showcasing the effectiveness of the 3D-printing technology in electromagnetics, with reference to UHF RFID technology. In [item (20) in the Appendix], Ria *et al.* described the design of a compact and low-profile ceramic UHF RFID tag antenna to be integrated into small cavities carved out of metal objects to identify themselves during the entire fabrication and assembly line. Specifically, an experimental analysis of the effect of high temperature on its performance is described and discussed, showing a significant chip input impedance variation by increasing the surrounding temperature with a consequent read-range reduction. However, the ceramic tag can be detected at a satisfactory distance of 30 cm when employed with temperatures so high as up to 120°C. A UHF RFID reader antenna capable of 2-dimensional (2D) beam-scanning from 0° to 360° in the azimuth plane, and 0° to 40° in the zenith plane was proposed in [item (21) in the Appendix] by Chen *et al.* They experimentally demonstrated that the antenna 2D beam-scanning ability and the improved AR performance lead to better tag-reading results, improving the percentage of missing tags by up to 21.6% compared to a standard antenna which has a degraded AR and only supports 1D beam-scanning.

Besides, other two papers are focused on antenna design for 5.8 GHz systems [items (22) and (23) in the Appendix]. In [item (22) in the Appendix], Haddadian and Scheytt presented the system and circuit level analysis and feasibility study of applying microwave RFID systems with multiple-input multiple-output (MIMO) reader technology, for tracking machining tools in multipath fading conditions of production environments. In the proposed system the MIMO reader interrogates single-antenna tags and a high RFID frequency of 5.8 GHz is chosen to reduce the size of the reader antenna array. In [item (23) in the Appendix], Passafiume *et al.* presented design principles for a totally batteryless and cost-effective wireless transponder, based on commercially-of-the-shelf (COTS) components. The transponder architecture is compliant with the physical layers of most common vehicular dedicated short-range communications (DSRC) applications operating at 5.8 GHz.

Finally, in [item (24) in the Appendix], Chou studied the wireless power transfer between two paired transmitting and receiving antenna arrays for high transferring efficiency when they are in the radiating near-field region of each other, as in some RFID applications.

Chipless RFID systems represents a niche technology within the framework of passive RFID solutions. Their increasing interest is due to their reduced cost with respect to classical passive RFID tags thank to the removal of the chip, which represents the most extensive part. To implement a chipless RFID system, the tag design is an important aspect [items (25) and (26) in the Appendix]. Paredes *et al.* [item (25) in the Appendix] designed a tag consisting of a chain of metal patches etched or printed on a dielectric substrate, and tag encoding is achieved by patch size. Lopes *et al.* [item (26) in the Appendix] presented a qualitative analysis of the impact of variations in the physical dimensions of gap coupled spiral resonators on the resonating frequency and attenuation level in multi-resonant circuits, aiming to simplify and make usable the design process of gap coupled spiral resonators for chipless RFID tags. However, the key aspect is represented by the decoding algorithms which influence on the real applicability of such chipless systems, as stated by Alencar *et al.* in [item (27) in the Appendix]. They determined the advantages and drawbacks in several decoding scheme, by pointing out, for the first time, the performance of the Short Time Prony Analysis for chipless RFID tag detection.

This article collection represents a good sampling of the main topics involving the RFID research groups, worldwide. Among them, localization systems, novel antenna design, tag sensing, biomedical and wearable sensors, augmented RFID systems and chipless represent the hot topics, by posing interesting challenges for researchers. The growing collaboration between the academic and industrial worlds represents the turning point for the massive diffusion of such a technology, bringing a number of benefits in several application scenarios.

We also would like to express our appreciation to all the authors who contributed to this Special Issue on the *IEEE RFID-TA 2019 Conference* with their extended papers.

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APPENDIX
RELATED WORK

1) A. Tzitzis, S. Megalou, S. Siachalou, E. Tsardoulias, A. Filotheou, T. Yioultsis, and A. G. Dimitriou, "Trajectory planning of a moving robot empowers 3D localization of RFID tags with a single antenna," *IEEE J. Radio Freq. Identif.*, vol. 4, no. 4, pp. 283–299, Dec. 2020.
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11) R. Horne and J. C. Batchelor, "A framework for a low power on body real-time sensor system using UHF RFID," *IEEE J. Radio Freq. Identif.*, vol. 4, no. 4, pp. 391–397, Dec. 2020.
12) C. Miozzi, F. Amato, and G. Marrocco, "Performance and durability of thread antennas as stretchable epidermal UHF RFID tags," *IEEE J. Radio Freq. Identif.*, vol. 4, no. 4, pp. 398–405, Dec. 2020.
13) M. Yu, X. Shang, M. Wang, Y. Liu, and T. T. Ye, "Exploiting embroidered UHF RFID antennas as deformation sensors," *IEEE J. Radio Freq. Identif.*, vol. 4, no. 4, pp. 406–413, Dec. 2020.
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